ON THE

Relation of Moisture in Air

—TO—

HEALTH AND COMFORT.

By ROBERT BRIGGS,

COR. MEM. AMERICAN INSTITUTE OF ARCHITECTS, ETC.

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ON THE RELATION OF MOISTURE IN AIR TO HEALTH AND COMFORT.[1]

By ROBT. BRIGGS, C. E., Cor. Mem. Am. Inst. of Architects, etc.

It may be accepted that the most pleasant condition of the air, in our portion of the globe, will be found to exist on a fair day in early summer, when the temperature ranges from 62° to 68° Fahr., and the moisture present in the air is from 85 to 80 per cent. of saturation. On a day like this, no thought of the weather is taken, and the passage of the conversational compliment of a "fine day" becomes a needless reminder, to be accepted without discussion or thought. Admitting this proposition as a fact, it is the purpose of this paper to show that in our climate this summer condition of relative heat and moisture is not desirable, or even attainable, at other seasons, in the ventilating or heating of occupied places. And in presenting this view to the American Society of Architects, I do so with a full knowledge that it does not accord with the opinion of most American writers on the subject of ventilation, who have derived their information and their arguments mainly from the study of English and French books, and have only endeavored to reconcile the data found in these to American wants and practice. Even Wyman, who is by far the most original as an observer, as well as the most thorough as the collator of information from all sources, hardly makes the distinctive effect of our low temperature, combined with a comparatively lower dew point, sufficiently evident.

Except one investigates the relation of moisture to temperature of air in the two countries, it is impossible to reconcile our facts with the statement of good foreign authorities,[ii] that 56° is comfortable,

[1] Paper read before the Am. Institute of Architects, at Boston, Oct. 18th, 1877.

[ii] The comfortable warmth of air indoors is given by various authorities, as follows: Peclet, "Traité de la Chaleur," gives 15° Cent., 59° Fahr. Morin, "Etudes sur la Ventilation," for nurseries, schools, etc., 59°; hospitals, 61° to 64°; theatres, assembly halls, etc., 66° to 68°! Tredgold, "Principles of Warming and Ventilating, etc.," 56° to 62°. Reed, "Illustrations of the Theory and Practice of Ventilation," 65°. Hood, "Treatise on Warming Buildings, etc.," inferentially 55° to 58°. Parkes, "Manual of Military Hygiene," 48° to 70° (this author has encountered the difficulty of naming a fixed temperature, and avoids the issue). Box, "Practical Treatise on Heat," 62°. Others might be quoted, but these are amongst the best authorities on Heating and Ventilation.

and 62° is warm in living rooms in mid-winter; while the American shivers with cold at 70°, and is not overwarmed at 76° in the apartments of his own dwelling, although clad in the thickest of under-clothing. Investigation, however, shows that the deprivation of heat from the person is more due to evaporation from the lungs or throat, and from the skin, than from heat otherwise dispersed; whether carried off by the breath, imparted to the air, or radiated to surrounding objects. And further investigation will show that the hygrometric state of the air has so much effect in inducing or retarding evaporation, as to make 56° Fahr. in the West and South of England, in Ireland and in Normandy, sensibly as warm as 80° in Canada or Minnesota at the same season. A brief statement of the difference of climatic condition of England and of America may show why we cannot import English theories of ventilation and heating, and apply them at once, without modification, to American residences. The English climate affords nearly eight months in every year, when the thermometer ranges between 40° and 60° in the shade, with a dew point so high, that it is a pleasure to exercise in the invigorating air; one month of 60° to 80°; and three months from 25° to 50°; there being no term, except a part of the one month of heat reaching to 80°, when any person cannot, with suitable clothing, enjoy the open air. While in America there is scarcely one month (or 30 days) out of the year, having an average temperature of 50° to 75° (which temperatures, from the difference of dew point, correspond sensibly with 40° to 60° in England); and there are three months of 75° to 90°; three months of 30° to 50°; and five months of excessive variation of temperature of from 0° to 50°. During the three hot months, and also during most of the five cold, open air exercise to those whose avocations are within doors, is, if not impossible, at least very uncomfortable, however clad or covered. Anyone, who is called upon to endure the fervid summer heat, or who can habituate himself to the inclemencies of our arctic winter, will not suffer great discomfort, nor experience much injury to his health therefrom; but the weak and tender—the merchant from his counting house, the student from his closet, the workman from the shop, the women and children of the house—cannot acquire the endurance or the habit, and must shelter and protect themselves.

This preamble to the subject has been intended to impress the fact that its consideration must be on its own merits, and not through the

light thrown upon it by general writers, that its investigation shall be original from physiological considerations, and not based upon authorities.

§ Comfort, if not existence, depends upon a constant loss of heat from the person. The internal natural warmth of the body is very nearly 100° Fahr., regardless of the heat of the external air, and the personal comfort which proceeds from the temperature and humid condition of the air, proceeds from the cooling effect which must then occur with constancy and regularity, and yet not so fast as to produce the sensation of cold. The origin of the natural heat is well established. There is inhaled by each adult in comparatively still life, each 3 to 4 seconds, from 30 to 40 cubic inches of air, at such temperature as may exist at the place, with extreme differences of temperature ranging from —40° to + 140° Fahr., and with extremely variable proportions of humidity, from the point of saturation on the one hand to that of nearly an anhydrous air on the other. The practical extremes in our country are from little below zero to about 100°, accompanied also with great variation of humid condition. A portion of the oxygen of the inhaled air is consumed in the system; and the exhalation, which follows each inhalation, emits about 4 per cent. of carbonic acid, and $1\frac{1}{2}$ per cent. of vapor of water. Two or three grains of carbon are consumed in the system each minute, giving out $3\frac{3}{4}$ to $5\frac{3}{4}$ units of heat; the unit of heat being the equivalent to a pound of water heated 1° Fahr. It is the dispersion of this heat which establishes the sensation of comfort. Modern theory has established the convertibility of heat to work or power, and some portion of the heat evolved by the air of respiration will have been converted into labor or effort, but far the greatest portion will have been utilized in preserving the temperature of the body from the losses by evaporation of moisture, by conduction and by radiation. One portion of the loss is readily estimated. The breath is inhaled at whatever temperature and humidity may subsist at the place, but is exhaled at all times at 90° (when the temperature of the air is not above that degree), and it is saturated with moisture at that temperature. If it is supposed that the temperature of the external air is 62°, and the dew point 54° (= 65 per cent. humidity), from 0·35 to 0·56 unit of heat will have been expended in evaporation of moisture in the lungs and throat, and 0·10 to 0·17 unit of heat in imparting heat to the exhaled air each minute. About $3\frac{1}{2}$ times as much heat will have

been expended in supplying the moisture, as in heating the air. The loss of other portions of heat cannot be as definitely estimated. It is evident that it must mainly be dispersed from the skin, and it is pretty certain that a large, if not much the larger, portion must pass off in insensible perspiration, which will be greatly affected by the condition of humidity of the surrounding air. Here clothing becomes an important element. We protect ourselves against the inclemency of winter, or the heat of summer, by coverings more or less non-conducting or non-radiating, leaving but a small portion of the person unprotected by direct exposure. An almost instinctive preference is given by all people, of all times, and at all places, for porous clothing; even the skins which clothe the inhabitants of the coldest regions, although quite impervious to moisture and to currents of air, are very open for the passage of vapor of water, or of diffused gases. Evaporation, and consequent cooling of the skin, takes place in great measure, or is influenced by the relative vacuum which the quantity of vapor present in the air establishes. The transfer of vapor is then one of diffusion, and follows the law of diffusion of gaseous bodies. A partially anhydrous air, external to the clothing, is a partial vacuum to the vapor of 90°, existing in ducts of perspiration, and this vapor rushes towards the vacuity without encountering the resistance of any circulation, and meets no considerable obstacle in the porous coats and overcoats. It is in this way possible to explain why, in mid-winter, with the room from 65° to 70°, heavy underclothing is not only endurable, but necessary. The overcoat may be removed on entering the well warmed house, but no discomfort follows from the retention of warm garments, that, with a summer condition of air of the same temperature, would be oppressive. We sleep in rooms, which, if not warmed to the full heat of our living rooms, have yet the "temperate" point of indication by the thermometer, and in this case enjoy a pile of bed clothing, which would be suffocating in weather of the same natural temperature. The American requirement of comfortable drawing room clothing is strikingly different from that of England. The ladies' English drawing room dress is an impossibility in America. Even the rigorous laws of fashion fail to conform themselves in this case, and yet our American drawing rooms are *hotter* than the English ones.

What proportion of the heat generated by formation of carbonic acid to be dispersed from the body after taking out what is abstracted

by exhalation and by labor of work or animal life, is expended in vaporization of water, is of course doubtful. Some authorities give 2 to $2\frac{1}{2}$ lbs. of water to be evaporated, each day, by insensible perspiration. These quantities would give (nearly) 2000 to 2500 units, or $1\frac{1}{2}$ to $1\frac{3}{4}$ units of heat per minute, and, together with the quantity of heat dispersed in breathing (on the previous supposition), account for one-half of the heat produced; leaving one-half the heat to be dispersed in work, life, or conduction to air, or radiation to other bodies. These authorities quoted are, however, English, and it is uncertain what quantity of moisture is evaporated from the skin in heated rooms in mid-winter in our climate.

It is probable that in still air, with the person in repose, the transfer of heat, either from the person or the clothing, whether from radiation or from conduction, is nearly equal; but in any current of air or movement of the individual, the effect of conduction will much exceed that from radiation. It should be remembered, however, that a current of air always exists about any person. The comfortable temperature of the air being lower than that of the person, there is established, by the heat imparted to the air by the person, an ascensional current surrounding and enveloping him, sufficiently defined to be measurable by a delicate anemometer, which is effective in augmenting considerably the convection of heat over what would occur in entirely still air. Assuming any comfortable temperature for air between 60° to 80°, the exhalations of breath by virtue of extra temperature and the presence of vapor to saturation, notwithstanding the addition of some carbonic acid gas of greater density than that of the air, are still so much lighter than the air as to ascend at once after the directional impulse from the mouth or nostrils will have expended itself, which, when the act of breathing has its normal force, and is not made violent by running or exertion, occurs within two feet.

In all cases the sensibility to loss of heat, whether from the breath as exhaled moisture or heated air, or from the person as evaporation from the skin, or as conduction to air, or by radiation to cooler objects, this sensibility, I say, varies in the several regards with different persons, with different races or nations, and above all, with the habits from business pursuits or occupations, or the customs or fashions of the place of living; any of which causes may and will have established a regime in each individual, and their comfort will

depend upon conformity thereto. The occupation, business or habits of individuals as regards their labor or exercise, both when at labor or exercise, or when at rest, cause much discrepancy in demands for heat. In the coldest and dryest day, few young persons can fail to warm themselves to the point of comfort in skating—many of the trades demand special temperatures for the workmen, some requiring special temperature and moisture condition of the air for the work—to which temperature and condition the workmen must conform.

There are three means provided for the healthful dispersion of animal heat into the atmosphere; the first is radiation to surrounding colder objects; the second, conduction to the atmosphere, which, for comfort, must be sensibly cooler than the body, and the third is evaporation from the moist surfaces of the lungs, throat, and the roots of the pores of the skin. The first of these means, to the clothed person at least, is comparatively ineffective, while the relative quantities of heat which may be eliminated in any given time or locality, by the two last, will probably be found nearly equal in an atmosphere of about 70° temperature and 65 to 70 per cent. of humidity. In all cases of *excess* of animal heat, the animal, and mankind as an animal, find relief in evaporation of water secreted in the system, showing that vaporization is the ultimate means of dispersion of heat.

Even the races of animals exhibit diversity of natural methods of dispersing the surplus animal heat. Thus the dog obtains relief through the breathing functions, and extends the surface of evaporation by exposure of the tongue, while the horse breaks out into profuse perspiration of the skin.

The relation of what is indicated by the sense of cold or warm to definite temperature with varied proportions of humidity, may be examined at this stage of the argument. Considering a nearly saturated atmosphere, it will be found that its effects differ with the temperature altogether. Such an atmosphere at from 35° to 50° is found to be intolerably chilly, and although evaporation may be checked, and this source of loss of heat be removed, yet the conductive and radiating value of the vapor in the air is now elevated enormously. The cooled surface of the cuticle absorbs the natural heat of the skin, and represses the evaporation of secretions almost entirely. An actual transfer of heat from the skin to the vapor in contact with the surface occurs, the superheated vapor no longer rushes away from the skin, in search of that vacuum, which is the

accompaniment of a usually low dew point, but merely transfers its heat to the next particle of cold vapor, which is packed in convenient juxtaposition to receive it; or else an actual movement of the heated vapor effects a circulation or current which brings a new cold particle to receive a new increment of heat. In an atmosphere of this nature, the exhaled breath, and the exhaust steam from the workshops, evolve a cloud of apparent vapor, which must condense in cooling as the air absorbs its heat, for the saturation of the air forbids its absorption as an invisible gas. A Scotch mist of 36° (which is only a supersaturated air with vapor in excess at a slightly higher temperature than the air) penetrates clothing, and reaches every part of the person with distressing frigidity.

Passing upwards in the scale of temperatures from 50° to 65°, the point of equilibrium of cooling action by conduction or radiation of vapor in the air, with supply of heat from checked evaporation of the skin or lungs for attainment of comfort, seems to be reached. Perhaps the most healthful, or at least most stimulating, atmosphere for human breathing is found within these limits, when of natural and continued existence, so that within and without the doors the same condition exists, and the regime of the bodily system is not disturbed from hour to hour. This, if not the ruling climatric condition of English life, at least is the presumed theoretic standard of English writers. Mental or physical exercise, alike, either separately or in conjunction, are supported by this condition of the atmosphere to an extent which no inhabitant of the frigid north, or enervating south, can imagine.

Some curious physiological phenomena accompany this atmospheric condition, one of which is the possibility of use of stimulants of the milder nature (wine and malt liquors), in quantities which would be immoderate in our climate. With the comparative cessation of cutaneous evaporation, it seems as if action of the alcoholic ingredient of the liquors were much changed and rendered more stimulating and less intoxicating.

From 65° to 80° a saturated atmosphere is sultry and oppressive. The surplussage of heat cannot be removed by conduction, and the natural effort of the system is to induce evaporation. The least physical effort produces, in the healthy person, abundant sensible perspiration, and the cooling effect of evaporation of a heated surface of water into a cooler air is the natural remedy. The lassitude and

enervation of this step in the scale is eminently unfavorable to mental as well as to physical labor.

Above 80° a saturated air becomes burdensome; it is even questionable if life could be prolonged in a saturated air of 90° to 100°, and it is certain that at some point, not much above 100°, suffocation would ensue when any exertion should raise the animal heat above its normal degree. The deaths in the Black Hole of Calcutta were the result of excess of moisture, rather than of heat, or want of air *per se*. There are travelers' tales of regions on the Red Sea, and near the mouth of the Persian Gulf, where men cannot breathe in summer for the heat combined with moisture.

In the same way that the effect of a nearly saturated atmosphere has been examined, that of a very dry one may be investigated. To the sense of feeling all air may be said to be dry below 35°. The small amount of vapor present, and possible to exist as vapor below this point, reduces the conductivity so that the chilliness, to a great degree, disappears, even in a saturated air. Yet even here the cold producing effect of a high dew point is felt in a wind, so that from 15° to 35° the N. E. wind of our Eastern states is a very raw one.. But, on the other hand, with a dry air from 40° below zero to the freezing point, the immediate sensation of cold by the active man, well clad with porous clothing, is yet endurable, and with habit becomes almost pleasant. Still these temperatures are not those suited to civilized life, either physical or mental. As has been before noticed, we have in the Northern states about five months of the year, when the temperature ranges from 0° to 50°, and consequently when our civilized avocations demand artificial heating. The winter climate of the Eastern, Northern and Middle states, is one of great vicissitudes, with extremes, both of temperature and of hygrometric conditions following each other rapidly. In the Northwestern states, it seems that a somewhat greater uniformity of temperature, and a much more uniform hygrometry, exist during the winter months, but in the Middle Western states the irregularities appear to be as frequent as in the Eastern states. Except that the length of the winter season is a little cut short, and the excessive cold is a little alleviated in the southern portion of the belt of country I have designated, much the same phenomena of climate exist all through the states north of the 40th parallel of latitude. Throughout this territory it has become recognized that the minimum temperature of comfort for heated and ven-

tilated rooms can be stated at 70°, with an admitted, and generally supposed inexplicable, if not unreasonable, demand, for 75° to 78° in some localities and at some times.

§ Ventilation means a supply of fresh air to the occupants of a house, workshop or meeting room of any kind; and as a final result, the quantity of such supply needed to attain the desired purity is from 40 to 60 cubic feet of air for each person each minute, where the contents of the rooms can be considered as furnishing a portion of the supply when occupancy is only for a part of the time. Much of the air may not be supplied through the heating apparatus. In cold weather, when the levity of the heated air within a building, compared with the colder air on the outside, produces a great pressure of outer air near the ground, the leakage of air at cracks of the door and window frames, at the top of the building, and its replacement by colder air through similar apertures at the bottom, furnish a much larger volume of air than is generally supposed. The strong winds also seek such leaks. Some permeability of walls, even of boards well painted, is available for the diffusion of vapor and of gases in a measure. So that the proper quantity of air to be supplied by an apparatus, becomes a question to be considered, in each instance, on its own merits. But the fact still remains, that for each adult or child in health, 40 to 60 cubic feet of fresh air must be estimated as provided, either by arrangement or surreptitiously, for each minute they may occupy a room or place, although not necessarily during each minute of the day and night. This fresh air must be derived from out of doors.

Accept, for the sake of argument, the average temperature and dew point of Philadelphia, in January, February and March of 1844, as reported in Prof. Bache's meteorological and magnetic observations. The mean temperature of those three months was 34°, with an average dew point of 25°, barometer 30 inches from hourly observations, giving 68·8 per cent. of saturation. Using Guyot's Psychrometrical Tables, Regnault's data, 1·57 grains of aqueous vapor exist in a cubic foot of such air. These, in Philadelphia at this season, are the unquestioned properties of the air, from which is to be furnished the fresh air of ventilation. If heated to 70° without increment of moisture, the dew point remains unchanged, and the same 1·57 grains of moisture appertain to the enlarged volume of air, now increased 8·2 per cent. by expansion. The hygrometric condition of this air

is but 1·44 grains per cubic foot, or but 18 per cent. of saturation. The summer hygrometric condition of air can be derived from the same source. The three months of July, August and September give 71° average temperature, with 60° dew point, or 68·3 per cent. of saturation. Suppose we take the 68·3 per cent., and consider it the proper condition for the air of ventilation at 70°; it then follows that 5·46 grains of moisture should accompany each cubic foot of air in winter. One more step in calculation, and I have done. A cubic foot of air at 70° weighs 0·074 lbs., and if it has been elevated in temperature from 34° or 36°, then 0·635 unit of heat will have been expended in warming the air. Again, if the amount of moisture present in this cubic foot of air has been increased from 1·44 grains to 5·46 grains = 4·02 grains, then 0·612 unit of heat will have been expended in evaporation of water to supply the moisture to vaporize the air. The quantity of heat for warming very nearly corresponds with the quantity of heat for vaporization!! The tension of vapor of the external air at 34°, with 25° dew point, is 0·155 inch of mercury; that at 70°, with 59° dew point, is 0·515 inch of mercury. It follows that the pressure tending to diffuse the aqueous vapor from the "hydrated" room to the external air, would be 0·365 inch of mercury. The vapor itself, within the room at the same time, possesses but one-forty-eighth the tension of that of the air present, and hence, as it is endeavoring to escape under the pressure of about 25 lbs. per square foot (which corresponds to the 0·365 inch of mercury column), it becomes evident that it would diffuse through cracks, outlets, and even through the passages for supply of fresh air, with great rapidity, and that this ratio of saturation is practically impossible to maintain in any *ventilated* room, or even in any room whatever, as ordinarily enclosed and built.

These estimates and considerations show fairly what would result from the attempt to produce an artificial summer climate in the houses of our Northern states in winter; but while the futility of the effort in its complete accomplishment is made evident by them, it by no means follows that some degree of hydration of warmed air is not the requisite of health or of comfort, and the question recurs, what proportionate hydration is needed for these ends?

§ It is with some reluctance that I refer to the "Theory of Ventilation." The past eighty years have witnessed the growth of chemical science, which, after passing through numerous stages of development,

as witnessed by the different nomenclatures, has finally reached the point, that only the chemists of continual study can comprehend it, and at which point he who knows most about it is the least satisfied with its present condition.

But thirty or forty years since, chemistry was supposed to have unlocked the mysteries of matter, and by the extension of the simple rules applicable to the gaseous and metallic elements, it was thought that the cause of disease or health was to be discovered. Careful observers then examined, from the chemical standpoint, the constitution of the air, both fresh and vitiated: and writers, with good logical conclusions, enunciated a *Theory*, by which is was made evident that chemistry had uncovered the root of disease, and carbonic acid gas was the fatal cause.

The real facts are these: An adult in still life inhales each minute about 480 cubic inches of fresh air, and exhales 488 cubic inches of vitiated air, of which vitiated air about 4 per cent. is carbonic acid, and from which about 19 per cent. of the oxygen originally supplied by the fresh air has been abstracted; the original quantity of vapor in the fresh air at mean temperature and hygrometric condition (62° and 65 per cent.) will have been increased from 1·1 to 3·08 grains.

Carbonic acid gas was made the scapegoat. It killed dogs at the Grotto del Cane, as was happily exhibited to numerous travelers in Italy at that time—and both before and since, the same unfortunate dog serving to be killed, to the satisfaction of admirers, that had been resuscitated the day before, after the visitors' backs were turned. It was heavier than air, and in some conditions of temperature would not so readily diffuse, but form a layer of distinct gas, like water beneath oil. Altogether it answered the conditions of hypotheses, and it was decided to be vile, deleterious, poisonous. To be sure, we devoured it in bread and drank it in beer, or aerated waters, but then the poison was to the lungs, not to the stomach! This theory found promulgators in the lecture rooms, and advocates in the household thirty years ago, and has become to-day the *traditional* belief of the middle aged and elderly. If a room is hot or close from excess of temperature, or from a crowd of occupants, carbonic acid gas is the difficulty; if malaria is developed in a jail or hospital, or typhus or scarlet fever exist in the dwelling, carbonic acid gas in excess is the poison. "The gas is heavier than air, and must necessarily sink to the floor, where all the air of vitiation will be found." These notions

continue to have advocates and supporters to the present time, and the popular lecturer or writer gives a half assent to them, to secure the favorable opinion of audiences or readers. But step by step, during the past thirty years, it has come to be perceived that the causes of disease are not to be found with inorganic matter, and carbonic acid has been removed from its elevated place in ventilation, with the fullest admissions, that in the quantities ever present in the living rooms, except by accident, it is quite harmless; and finally, its presence has been accepted as merely a measure of other more dangerous vitiations, in that as it is a definite product of respiration, and as the proportion present in any room, at a given moment, can be ascertained with tolerable exactness, an indication can be derived thereby of the extent of organic vitiation with some degree of certainty.

The unquestioned theory of malaria, the meaning of which word can be extended to embrace diseases arising from deficient or defective ventilation, to-day, is organic vitiation, and the probability of this theory holding its place in future, is, I think, a very fair one. The exhaled and exuded vapor from the human body is known to be laden with organic matter; much of this organic matter is within the range of the microscope, by means of which the local derivation of many particles can be determined; but some of it is in the form of effluvia and odors, which pass the limits of visual observation in the smallness of the atoms, notwithstanding such effluvia or odors are decidedly perceptible to the sense of smell. With a dry external atmosphere and a reasonably free ventilation, the exuded vapor and the organic matter pass away, or are diffused as rapidly as supplied. *It should be remarked that the organic matter appears mainly to be in connection with the vapor in the air, and not to exist as a separate gas, diffused in the dry air when the vapor is removed by natural causes.* With an imperfect or insufficient ventilation, the upper parts of rooms become filled with air, which will be found to contain a much larger proportion of moisture than the lower portions, and will be shortly found to be exceedingly offensive from the rapid decomposition which the exuded organic matter undergoes in a moist air. This will happen more frequently when the internal and external temperatures are about the same, and when it is so cold, raw, or windy, as to require closed doors and windows, with only a small addition of heat, and when with these conditions the natural dew point is high. These circumstances are in concurrence frequently in

England, where probably 120 days out of 365 call for but small addition of heat in rooms, while they rarely exist with us; the climate of our northern United State not giving 30 days in any year of similar kind. The objection of *effluvia*, which forms the distinctive one in audience rooms in England, and is so noticeable to the American visitor of such rooms, is replaced in our halls by a simple sense of oppression—a mere feeling of discomfort—which, on the other hand, is particularly noticeable to the English visitor of our halls, who is apt to associate it with a supposed excess of heat.

But this organic matter of exhalation is still one step removed from malaria, it is only the ground of malaria—the soil on which a malarial growth will propagate; its *decomposition* is held to supply the means of fecundity to the germs of disease. In the warm air confined in the upper parts of rooms, with excess of moisture, it may undergo a rapid and somewhat fetid decomposition; under such circumstances it is found to become offensive in six to ten minutes. With a smaller proportion of moisture, or when it is rapidly absorbed with the moisture by diffusion into air of American dryness, it does not decompose so rapidly, but is likely to be absorbed by any hygroscopic substance the air containing it may come in contact with. The walls of rooms, especially the porous plastering, stone or bricks, and possibly the papered and painted walls, will take up the excess of moisture with its organisms, and give up at another time, wholly or in part, the moisture without them. There is a characteristic smell of walls of kitchens, cabinets, hospitals, jails, court rooms, and similar permanently occupied places, which can be developed in intensity by simply holding the half closed warm hand against the face of the wall, and testing the result by the sense of smell of the hand. In such instances of retention of the results of imperfect ventilation, the eventual propagation of disease is a certain one.

To the vegetable and lower animal growth, the presence of moisture in the air seems a positive necessity; where it is absent they perish, or at least no longer grow or propagate. The drinking animal apparently suffers the least of injury, and but little discomfort in the dryness of the air of whatever temperature. The immunity from disease to the human race which accompanies the dryer regions of the earth, has been frequently remarked, and the fact meets general assent. The discomfort of the colder countries, even to the limits of the arctic regions, is one of cold, not of absence of moisture. The

assertion of relative insensibility to cold air devoid of moisture, is the common report of all travelers in such regions; while the dreaded malarial diseases of more genial lands do not exist in them at all. In the temperate zone, in countries or localities which possess the dryest of atmospheres, with the least variation of hygrometric condition, mankind is most free from disease of all descriptions. The elevated dry and barren lands of our midland country, from Minnesota southwardly, are the healthiest regions of the United States; and where, together with the *dry* atmosphere, some uniformity of temperature exists, as in Mexico—where the height above the level of the sea reduces the sensible heat of the air, which is usually found in that latitude, to a comfortable one—there we have the acknowledged climate of utmost healthfulness. Going into more torrid lands, the dryness of the air alleviates the heat of the deserts of Arabia, and of Africa, of Peru and Bolivia, where the temperature rises at times to 110° or even 120° in the shade. I have the assertion of a friend that on a hot day, with the thermometer nearly 100°, he has known the wind on the Arabian desert to be searchingly cold, when everything was shriveling up for want of moisture. My attention was called by Dr. J. S. Billings to the following extract of his report on the Hygiene of the U. S. Army in 1875:—"Description of military posts, Fort Yuma, California. Reports of Asst. Surgeons Lauderdale and Ross, U. S. A. After describing the locality of the post, near the junction of the Giler and Colorado Rivers, they say: * * * 'The heat increases rapidly from the latter part of May, and in June, July, August and September may be said to be intense * * During the months of April, May and June no rain falls; then, with the thermometer at 105°, the perspiration is scarcely seen upon the skin, and it becomes dry and hard, and the hair crispy, and furniture falls to pieces, * * ink dries so rapidly upon the pen that it requires washing off every few minutes. * * A No. 2 Faber's pencil leaves no more trace on paper than a piece of anthracite, and it is necessary to keep one immersed in water while using one that has been standing in water some time. Newspapers require to be handled with care, if rudely handled they break. Twelve pound boxes of soap, when reweighed, gave but ten pounds. Hams had lost 12 per cent. and rice 2 per cent. of original weight. Eggs that had been on hand for a few weeks lose their watery contents by evaporation, the remainder

is tough and hard; this has probably led to the story that our hens lay hard boiled eggs.

"'The mercury gained its highest point last summer on the 2d day of July, when for two hours it stood at 113° in the shade. All metallic bodies were hot to the touch, my watch felt like a hot boiled egg in my pocket * * *

"'This post, although not the most southerly, is the hottest military post in the United States; the highest temperature recorded on our books since 1850, when the post was established, is 119°, observed at 2.25 P. M., June 16th, 1859. A temperature of 100° may exist at Fort Yuma for weeks in succession and there will be no additional cases of sickness in consequence * * * We have none of the malarial diseases * * No ice is formed at any time; 29° has been indicated by a registering thermometer in January, 1872. The mean temperature, day and night, of January, however, is 57°; that of July is 95°. The average rainfall during four years was a little over 2 inches each year.'"

Any who wish to corroborate or question these views as to the healthiness or unhealthiness of dry air, hot or cold, can examine authorities, or investigate or observe for themselves; the conclusions they will reach can be confidently anticipated. But the proof or argument cannot be further extended in this paper, and it must be claimed that there exist good grounds to believe that dry air, *per se*, of whatever temperature it may be found on the surface of the earth, is not unhealthy; that, as regards disease, such air possesses both preventive and curative qualities of great value; and that, on the other hand, moist air, such as promotes vegetable growth, is not desirable for breathing on sanitary grounds. Asserting these views, the question narrows down to: given a habitat or place of residence, where some degree of moisture and vegetation does thrive for a portion of the year, at least—what effect on the system do the variations of moisture produce, from season to season, from day to day, and during such of the seasons as the comfort of inhabitants may call for artificial warmth, from one place to another on the same day?

§ Clothing, houses and fires are the means by which mankind is enabled to inhabit the face of the earth. It is an artificial existence for an animal whose natural life would otherwise be limited to a small belt of the torrid zone, where the temperature never falls below about 80°, nor rises above 100°. As residents of the northern United

States, we cannot expect to avoid, and do not expect to ameliorate, the vicissitudes of climate *out of doors*. Hot or cold, rainy or dry, with air relatively humid or otherwise, life in all countries means endurance under artificial guards or protections from natural inclemencies. We clothe ourselves by the umbrella on the one hand, or the great coat on the other; open or close our doors; induce cool breezes, or gather around fires, in search of the *comfortable uniform* loss of heat by the system. The efforts to accomplish this end, by means of change of temperature or relative moisture of the air, are of necessity confined to the cold, or at least cool, season, with infrequent attempts to obtain an artificial degree of cold in extreme hot weather. In moderate weather, the vicissitudes of temperature, and of humid condition of the air, are endured with the expression of discomfort and the tacit admission, on all hands, that our great day-by-day variations of the mild season are harmful to the feeble or sickly. But these daily changes of temperature and of hygrometric condition are of small account with those which in the Northern states accompany the season of cold. The change of climate from that which accompanies, during any of the winter months, our warm south winds, to that which accompanies a great northwestern wind wave which may follow the southerly breeze within twelve hours; a change from 50° to 60°, with 80 per cent. saturation, to even below zero, with an unascertainable dew point: such a change is trying to the extreme. The prevalent disease of the land is consumption of the lungs, and these changes are disastrous to those who are suffering from this complaint; and, to the healthy, these changes are held to be fraught with danger.

§ A very simple and commonplace observation will make the general condition of air in rooms in winter, as regards humidity, the subject of positive demonstration. During the season of winter in our climate, after a continued spell of cold weather, the exhibition of condensed moisture or of frost on the window panes is very unfrequent. The usual provision of glass in windows throughout the northern United States, is in single thickness, not double plates; the latter arrangement being decidedly exceptional as a means of preventing transfer and loss of heat at the windows. The temperature of a pane of glass which is interposed between two temperatures of still air, that is of air devoid of currents, except those generated by the differences of temperatures of the air on either side, and the

glass, is obviously that of a mean between the said two temperatures of air. With so good a conductor as glass, and with plates as thin as ordinary window glass, the conductivity of the glass may be assumed to be perfect, and both sides of a pane can be deemed to have the same mean temperature. But the temperature of the air on each side of a pane differs from either that of the external air on the one side, or of the room on the other. On the outside, the layer of cold air in contact with the pane ascends slowly as it is heated, and the vacuity which is formed at the bottom of a pane is supplied by fresh cold air, so that the layer at this point approximates to the temperature of the outer air closely. On the inside, the layer of warm air in contact with the pane descends as it is cooled, having, perhaps, an approximation to the inside temperature at the top of the pane, but by the time the layer has flown downwards to the bottom of the pane, its temperature will have become materially lower than that of air of the room generally. So that while the law of mean temperature of the pane at the bottom of the pane is yet good, the real temperature may be much lower than a simple mean between thermometers hung in the room and out of doors. Beside the supposition of still air, much allowance must be made for the effect of winter winds in accelerating the flow of cold air on the outside of the pane until the outer layer is very nearly of uniform coldness, which favors the greater abstraction of heat from the internal descending current, and cools down the lower part of the pane still further. Curtains, shades or internal blinds, while they aid in protecting the room from loss of heat, also protect the glass from acquiring the temperature due to the heat of the room. Until with the supposed case of external air at 10° above zero, and a moderate wind out of doors, and of a room warmed to 75° inside, the temperature of the panes near the bottom, or even well up their height, will be much below $42\frac{1}{2}°$ as the mean: and 27° to 28° may fairly be taken as giving the real temperature near the bottom. This pane of glass becomes then a dew point thermometer at all times in the winter, ready for indicating the humidity in the air. Except, however, a crowd of people, or some artificial "hydration" carried possibly to momentary excess under the stimulus of the last theorizer, or a very new house, or a damp cellar in an old one, we but rarely see any indication of presence of moisture in our dwellings in cold weather. This simple test will show that our dwellings, although the

water troughs of the hot air furnaces do supply limited quantities of vapor with admitted comfort, do not, as a rule, have over 30 to 40 per cent. of humidity in the air within them.

The entire range of our Atlantic coast is only removed from a region of perpetual spring from 200 to 500 miles; and a southeast wind, from December to April, may bring a vapor laden air, which, in a few hours, will have changed our frigid winter to a genial spring. The succeeding wave of northwest winds—a great current which the Signal Service has traced up to the Arctic regions—may, with great violence, restore the winter with all its rigor, within another few hours. Under this change, heavily frosted windows become the rule, and they indicate a dew point above the temperature of the panes of glass, at once. So dry and arid are these winds, however, that with the continuance of a northwest wind for a single day, all traces of window frosting will have disappeared.

This test of the dew point by the window, is very accurate. As an instance, I will quote that on one day in this present month, in Philadelphia, with the thermometer in-doors at 64°, without fire, a fall of temperature to 54° outside, produced immediate condensation on windows, showing 75° to 80° of humidity. Now if a difference of only 10° produces this indication for *humid* air, the want of such an indication with difference of up to 65°, must manifestly be a very dry air. By actual trial in well warmed and ventilated rooms, the writer has found the dew point far below the freezing point of water, in rooms where the sensation of dryness, which is held to accompany the heat of the furnace when not supplied with water for evaporation, certainly did not exist.

It is proper when alluding to the dampness of houses, to advert to one of the most striking differences between England and western Europe, and the northern United States, in the necessities which climate imposes in the relation of humidity in air to the health, in this particular regard. We find all foreign authors speaking in unequivocal language of the great danger of inhabiting a newly built and consequently imperfectly dried house. One English writer, whose name I cannot recall, but I remember to have been of much eminence, asserted that no house ought to be occupied until a year after completion. Many writers on ventilation join in estimating by figures the quantity of moisture in the new walls, and *demonstrate* the dangers of a residence, where the excess of moisture in the air, the

want of permeability of the walls, and the increase of conductivity of heat through the damp walls, will have produced such a tomb-like house. While in America we are fully alive to the danger in the house, from air overladen with moisture, as from a damp cellar, or location in a damp place or vicinity, and appreciate that rheumatism and consumption, with scarlet fever for the children in winter, when the house is thoroughly warmed, and typhus for adults in mild weather, are the possible, if not probable, penalties for living in such a house; yet the new house, from its inherent dampness, only is considered at least as but objectionable in a small degree. Except that dampness exists from other sources than that which comes from the walls, our new houses are quite as healthy during the first year, or the first season's occupation, as afterwards. No preliminary drying out is needed as a rule. Our summers or winters are dry enough to take up all the moisture which walls may give, without overlading the air with humidity; although it is noticeable, that new houses require more fuel to warm them the first winter than afterwards, as the supply of heat must be sufficient to evaporate an excess of moisture, and the conductivity of the walls is somewhat greater before they are thoroughly dried out. Few dwellings are completed for occupancy at the end of winter or of summer—residence generally begins with the beginning of summer or of winter, and the seasons when the dampness of walls would be dangerous from the existence of a humid air are not those when new houses are generally first occupied.

§ Although not directly related to the subject, I will mention here one curious demonstration of the effect of atmospheric humidity and impurity which is peculiar and common in England. All American readers, or observers, become aware of the great importance attached by the English public, as a people, as writers, and as a government, to the relative purity of illuminating gas, but it is not generally known, or even asserted, that the cause in England which makes the impurities of gas obvious, and renders them seriously objectionable, is to be found in the air of the room, and not alone or even mainly in the gas itself. The sense of oppression from the burning of gas in dwellings in England, is one that can be appreciated only by being felt; any description fails to convey to the mind of the untraveled American, the burden on the breathing functions which results from gas burning in a humid and impure air. It is enough to say that throughout England, gas lighting is regarded as only suitable for shops, workrooms, warehouses, public

rooms and such other places, within or without of doors, as demand light for passengers, rather than for occupants. When halls are lighted by gas, the chandeliers (gasoliers is the English word) and bracket lights are not considered to be well arranged unless "ventilated;" in other words, provided with especial means—air passages or outlets—for removal of the gases of combustion, with the accompaniment of a volume of heated air. The dwellings—dining and drawing rooms, passages, and chambers—of the more wealthy, are lighted nearly universally by candles of wax, sperm, or some prepared fatty substance, either animal, vegetable or mineral, with the occasional or frequent use of the carcel-lamp as a table light. From any English gas light there arises a current of impurities which in a brief space of time discolors, and coats with black, the interior of the ventilating tubes, or, in absence of such protectors, the canopies of glass or metal which are usually supplied for unventilated burners; or when this last protection is wanting, the ceiling, even when several feet above the burner, is quickly marked by a halo of greasy soot, which adheres to it where the ascending current impinges.

The heat emanating from a gas burner, as compared to that from a number of candles giving the same amount of light, is very nearly the same, about seven per cent. more heat being given out by the candles; but the 14 to 16 candles, which represent the single gas burner, will have been dispersed about a room, or even when grouped in threes or sevens, as usual in sconces, candelabra or chandeliers, will be spread widely asunder, so that the current proceeding upwards from each separate candle will have become diffused before reaching the ceiling; and, if the candles give out the same impurities (which they do not) as the gas burners, the obvious impurities which make a mark will not be precipitated to show themselves as spots. Besides this, a room lighted by candles will be considered brilliantly illuminated by three or four candles, where one gas burner would have been used; so that one-fourth the quantity of light will be made to suffice with candle illumination, to what is requisite for gas lighting. The numerous candles come in proximity to the objects to be lighted, while the gas burner, with its volume of light and of heat, must be further removed to be tolerable; and there is an actual requirement for more light from the latter than the former source to give the same effect in the room. The other substitute for the gas burner, the carcel-lamp, is frequently used in England as the centre-piece,

singly or in numbers, of the tables in the dining room, drawing room, or library. Its illuminating power is about two-thirds that of a gas burner, and the quantity of heat given out bears very nearly the same relation, that is, the heat from a carcel-lamp is about two-thirds that from a single gas burner of 14 to 16 candle power. As the carcel-lamp is movable in a room, and is usually placed low down, the chance of the current of air proceeding from it defacing the ceiling, is much less than from a fixed gas burner, in its usual position of height from the floor.

What may be the exact physical or chemical conditions accompanying the manifestation of *bad* gas in England might call for a long discussion in reply. It can be said at once that the indications on the ceilings are almost entirely those of atmospheric impurities and condensation of water. Soot, dust and organic matter in suspension in a saturated humid air—wherein the humidity is the vehicle which carries these substances, and is not free to disperse them from the general saturation—will be and are deposited on the first object of cooling and contact. This view of the case is not a mere guess. The fact that there is a general discoloration of ceilings from gas burners in England, as contrasted with those of the continent, where the air is uniformly a little more dry, and where the use of bituminous coal is unknown, so that its particles of carbon dust do not form a part of the common impurities of the air: and also as contrasted with the ceilings in this country: this fact is certain, and from it the connection of pure air with the *cleanliness* of gas burning is made evident. While English gas is much more carefully purified and treated than any in the world, the standard of its excellence is not only the highest, but it is made strictly up to this standard. Yet any sulphurous or sulphuric acids which emanate from gas lights, are at once absorbed by the vapor present, and if the atmospheric condition does not facilitate the diffusion of this vapor, these acids are retained in the ascending column to exert their energies on the objects of first contact, and afterwards retained in the room to act generally on any sulphur absorbent, colors or materials, as they do in England and do not in this country. It is probable in our climate, and in that of the continent, much of the humidity of combustion, and of the deleterious gases either evolved by, or inherent to, the illuminating gas—as well as the organic impurities, dust or soot, in the air burnt or heated by the act of burning—is diffused at once into the tenuious vapor of

the surrounding air. Not only before passing four or five feet from the burner, so that no condensation takes place on the ceiling, but also so thoroughly diffused as to prevent, in great degree, those chemical actions which prove so objectionable from the burning of the best purified coal gas in England.

§ It has been shown how nearly impracticable it is to procure, in winter, with the average temperature of winter, which is 34°, a summer temperature and humidity in our houses. The difficulties of effecting this with 34° for the temperature of the external air are enhanced greatly, as the minimums of cold are reached, and at zero the production of a summer air in a house or place of residence may be claimed to be impossible. If the effect of the changes of out of door temperatures and humidities, which can happen with, at the worst, eight to twelve hours of change, and which, on the average gives twenty-four to seventy-two hours of interval, is as objectionable: what words can express the effect of the mere passing from a room at summer humid warmth to the open anhydrous air at zero? There are few readers of this paper, who have not tried the experiment of leaving some crowded hall, where the closed doors and windows, and many breaths, had made an approach to the summer condition, and felt the cold air of winter at the bottom of the lungs, as the inactive membrane parted with its unexpected supply of moisture to the anhydrous air. At whatever temperature or moisture condition air be inhaled, it will be exhaled at 90°, and laden with moisture nearly to the point of saturation. Of the heat given out by the lungs, that which proceeds from evaporation is generally largely in excess of what is required to impart heat to the air. Even in the extreme case of breathing air at — 40° (or the temperature when mercury freezes, which the writer once observed at Vassalborough, Maine), the heat of evaporation of moisture from the lungs is but a little greater than that for heating the air, being 2·22 units in one case, to 2·18 units in the other, per cubic foot of exhaled air. The skin gives out its heat through insensible perspiration, or through heat imparted to air, in similar, if not the same, proportion.

The establishment of a regime of evaporation from the lungs or skin —of a constancy of secretions—appears to be more essential than the establishment of a uniform temperature, either of the air of respiration or of contact with the person. The stability of the moisture condition, whether in the external air from time to time, or between

inside and outside of the room, is what is desirable for health; and this stability, from inside to outside of room, is what we must maintain if we are to live in active, healthful life in our climate. The transfer of heat through the skin or membranes is merely conductive, not involving organic action; while the supply of moisture incident to the maintaining of evaporation, brings into service, vessels, ducts or pores, whose healthful action depends, in great measure, on the regularity and continuity of the said service. This hypothesis will explain at once the healthfulness of the climate of Florida or that of Minnesota in cases of pulmonary disease, and in other parts of the country will account for the prevalence of colds and coughs or the occurrence of rheumatic affections. The diseases of the changeable climate and water-laden winds of our colder Eastern states are bronchial and pulmonary; and (without desiring to intrench on the province of the medical profession, whose known duty at all times it has been to find the cause of disease) it may be safe to attribute them, to a great extent, to the effect of alternate dry and damp air on the evaporating surface of the lungs when the skin has the protection of clothing to keep it warm. The diseases of the warmer mountain-sides of our Middle states, are rheumatic, and may be attributed to the same cause operating, by warm currents of air, on the less unprotected skin.

Beside this view it can be averred that, for the resident or native of any country, there will have established, as a habit, a connection of moisture of air relative to its temperature which is national, so to speak, in which the *variations* of humidity and heat are accepted as a general average. Thus, the American in England is chilled to great discomfort by the low temperature endured by Englishmen, whose systematic evaporation provides for small loss of heat; while the Englishman in America finds a suffocating heat in the dwelling of the American, from the fact that his lungs and skin do not afford the moisture requisite for evaporation and consequent dispersion of heat. A long residence, often two or more years, is needed before the system of either is adapted to the novel condition.

§ Although somewhat late in the course of this argument, and perhaps somewhat elementary as information, it may be well to state the physical laws of the relation of moisture to air. The property of water is to possess in contact with itself, at any and all temperatures, from the boiling point downwards, an atmosphere of vapor.

which vapor has an elastic force, or exerts a pressure bearing some definite relation to the sensible temperature of the water and of itself. The English measures of this elastic force are generally expressed in inches of height of a mercury column, in the same way as shown by an English barometer, which of course applies to any unit of surface, and may be transformed to pressure in pounds per square inch or square foot, by a similar process to what we use for atmospheric pressures. According to Regnault (as quoted in Guyot's tables), some of the elastic forces are as follows:

DEGREES FAHRENHEIT.

—30	—20	—10	0	10	20	32	40	50	60	70	80	90	100	212
0·0092	0·0163	0·0270	0·0434	0·0684	0·1078	0·1811	0·2476	0·3608	0·5179	0·7329	1·0232	1·4097	1·9179	2·9922

INCHES OF MERCURY COLUMN.

From which it will be seen that the elastic force falls off rapidly with the temperature. At any given temperature, vapor, possessing the above value of elastic force, exists in the atmosphere as a part of its volume, *whenever there is water present to supply it*, and such an atmosphere is said to be saturated. When there is not sufficient water at hand to supply the vapor due to the temperature; what there is of vapor in the air is slightly superheated, as it accepts the temperature of the air and not that of its tension, but this effect is so small that it may be neglected. The air is then said to be dry; the usual way of estimating such dryness is by naming the percentage of vapor present, to that which would fully saturate the air at a given temperature. Dry air seeks moisture from any source, and the difference of elastic forces, between that of the vapor in the air at any time, and that of saturation of the same air, represents the *avidity* for moisture of such dry air as a species of partial vacuum.

Now the quantity of moisture as vapor accompanying a given quantity of air is neither increased nor diminished in the same air by heating or cooling it (of course in the latter case to the temperature when the air is saturated, below which point the moisture condenses). Hence it does not matter, so far as moisture is concerned, at what degree of heat we introduce the air for warming a room; if only the final temperature of the room be 70° or 80°, then the drying effect of the air of that room upon the persons occupying it, or its furniture, or its materials of construction, is that due to air of 70° or 80°, which air shall contain only the normal moisture of supply. In other

words, our hot air furnaces which supply air at 150° to 200°, do not (except, perhaps, close to the mouths of supply, before the heat is distributed) dry up wood-work or absorb any more moisture from the persons occupying a room, any more than do currents at 80° or 90°, provided the general temperature of the room is the same in both cases. But a yet more important truism can be stated, which is that the drying effect of air of a ventilated room at 70° or 80° which has received no increase of humidity in the hot air of ventilation from out of doors—air that has been warmed artificially from zero let us say—the drying effect of this heated air upon a person occupying it is very nearly the same as if he or she were to maintain the same temperature through active exercise and warm clothing out of doors. The exception expressed by "very nearly," relates to the clad portion of the body—the obstacle presented by the clothing to the free diffusion of aqueous vapor is more effective between the cold air which is but little warmed to demand moisture, and the skin which will give it out if the vacuum demands it, than between the arid air of the room which takes up every particle of moisture as it transpires through the clothing. As regards loss of moisture from the throat or lungs, however, there is absolutely no difference in breathing the air of the supposed room and that which is then found out of doors, although the one be at 70° to 80° and the other at zero; reiterating the former statement: "In either case the exhaled breath is at 90° as it passes out from the nostrils or lips, and is saturated or nearly saturated with moisture." No one ventures to assert that it is unhealthy, as an act of breathing, for the human race to breathe freely the coldest dry air of winter, because of the supplying of moisture to the anhydrous air. There is an evident fallacy in the assumption that it can be healthy to check instantly that copious secretion which has been supplying moisture to the fresh cold air of zero, by going into a room of summer hygrometric condition, or to demand such an effort of the tissue of the lungs suddenly by leaving such a room for the outer air. Fortunately, nature is more lenient than the theorists, and we do not get 70° to 80° with 70 per cent. of saturation in the most unventilated or uncomfortably heated houses, and with all efforts to the contrary, even 40 per cent. is of unusual attainment when the external air has a temperature of zero.

It must be admitted, however, that some small degree of hydration is a necessity for comfort, and with comfort for a demand, some reason

may be found to establish the healthfulness of the small supply. It is certain from all experience that from 5 to 10 per cent. of moisture can be added to air after it is heated, certainly with much relief, especially to the eyes, with apparently little harm, although such addition may make the occupant of a heated room a little delicate as to out-door exposure. Moisture may to some small extent be abstracted by the means of heating, especially when the heating is by stoves or hot air furnaces; at all events the presence of a sheet or surface of water over which the heated air is allowed to pass, is now a recognized means of supplying a small quantity of aqueous vapor to air of ventilation. But the quantity supplied in this way is very small in comparison with what is needed for complete "hydration," or even for what can be denominated "hydration" at all, in the sense of a summer condition. From an estimate based on several winters' experience, a vaporization of water which supplied a half grain of vapor per cubic foot of air introduced, when an increment of four to six grains for the same volume of air would be requisite to get the summer condition of humidity corresponding to the internal temperature, has proved sufficient to give a sensibly pleasant air, while the absence of this supply was at once perceptible in the house. A low pressure hot water apparatus, whose temperature never reached the boiling point, and rarely exceeded 180°, giving heat to a large volume of fresh air, which, at the mouths of supply to the rooms, was not much above 90° at any time, was the source of heat.

§ It is very difficult to find any hypothesis which will account for this requirement of a small supply of vapor with heated air, when we admit, or can demonstrate, that the sufficient quantity to the senses is so far below what is needed for hydration, and so independent from the moisture condition of the air; for nearly the same small quantity of vaporization seems desirable in air heated from any temperature. The explanation of the offensiveness of heated air currents has been sought with much diligence, and, at times, causes have been assigned with much positiveness. One of the earliest of these explanations (but one which yet finds supporters) was found in the substitution of transferred or convected heat by currents of air for the radiant heat of fire. Open fires were to be restored as the means of securing pleasant air. The healthfulness and comfort of our ancestors were to come back to their degenerate children. Gathered around a blazing fire, roasted on one side and frozen on the

other; restricted to one fire in the house, as all the others *would* smoke; the chamber-heating apparatus reduced to the warming-pan; victims of rheumatism, sciatica, tic-douloureux and ague—the diseases of fifty years ago—the good old times were to come back. Alas! there were obstinate innovators, and the world would not be convinced of the advantages of radiant heat as the sole means of warming.

This point being established, at a later time, surfaces at high temperatures for imparting heat to the air of a room, either by ventilating currents or direct heating, including all fire-heated surfaces, together with steam-heated ones, above the boiling point, or 212°, were utterly condemned. Somebody discovered burnt atoms of dust in heated air, and its destructive, pernicious effect on the health was at once apparent! But the comfort of the community some way overruled the theory, and hot-air furnaces, with admitted deficiencies in quality of air, met greater favor than ever. It is allowed, generally, that the expensive steam-heating apparatus is at once the more pleasant, controllable and durable; and that the yet more expensive hot-water apparatus, with its great volumes of low temperature currents of air, is the best of all means of heating. The cost in fuel by these several apparatuses becomes nearly the same, for equal effects, in warming of houses.

The next demonstration was the chemical one. An occult effect is most conclusively, if not convincingly, explained by an occult cause. Ozone is a favorable object to carry a theory, and it really is possible, if we knew anything definite and certain about the origin or the effect of ozone; some relation of this phenomenon of the requiring the evaporation of a small quantity of water, when heating air, might be traced. But no blinder pathway in science was ever opened than the ozone one. After this came Deville and Troost's discovery of the permeability of some metals, when heated at, or nearly at, red heat, to some of the gases. In the language of one of the most prominent writers on ventilation, this "explains the very injurious and even poisonous effects produced by the use of stoves in the rooms of a dwelling!"

The last resort of the unreasoning theorizer in physics is always to electricity, and efforts have not been wanting to show that either the presence or the absence of electricity, in some form or condition, ought to have something to do with the discomfort arising from heated air.

The only answer to this hypothesis is that heated air is equally oppressive in entire absence of water supply, whether highly electrical or otherwise; our vicissitudes of climate and of humidity enabling a test of electric condition in extreme cases. There are times in any winter, in the Northern states, when it is possible to gather enough electricity, by walking over a carpet, to make the spark from the finger which will light a gas-light. The quantity of water demanded at such times by a heating apparatus, is no greater than at other times. There is not the least positive proof of relation of electricity to the healthfulness of air Altogether, the whole resolves itself to the reiteration of the bare fact, that it is comfortable to evaporate a small quantity of water in heated rooms, and that it can be done without marked injury to the occupants or to visitors. The quantity itself seems to be almost constant for all temperatures or hygromations of the air, and to be a slight addition only to the moisture in the normal air out of doors at any time.

§ The effect of draughts on currents of air upon any person exposed to them is materially modified by the hygrometric condition. In still air in winter the comfortable temperature of a room in general hygrometric condition has been stated at 70°, but a current of air upon the person at this temperature is uncomfortably cold from the rapid abstraction of heat, while in summer the same temperature, accompanied by the summer dew point, will be warm enough to demand light clothing, and a current of the same velocity will not be objectionable; in other words, draughts which cannot be tolerated in our houses in winter, become pleasant breezes in summer. Not only the speed or rate of velocity of the current of air is to be taken into account, but its avidity to take up moisture from the skin as indicated by its dew point. So long as the hygrometric condition of the air is such that will absorb moisture below 98°, a blast of it at some rate of current will be a cool one.

One fans himself in our climate, when the thermometer stands at 100°, with a sensation of relief. This feeling of cold, from air of high temperature, when in motion, proceeds from the rapid removal of the stratum of warm and nearly saturated air in contact with the person, and its replacement by fresh air, which is not only cooler, but which has not yet become saturated or charged with moisture by contact with a moist surface like that of the skin. In no one of the changes in the three forms of matter—solid, liquid and gaseous—is there so

much heat taken up as in the change from a liquid to a gaseous (or vaporous) form, and in no other body or substance is so much heat absorbed or become latent as in the formation of steam from water, or in other words in the process of evaporation; and the quantity of heat taken up by the moisture which a dry air abstracts from the skin is so great, that the mere differences of temperature of the air, from that of the skin, may almost be neglected in the statement: and it is very nearly correct to assert that the cool sensation from a breeze in summer, proceeds entirely from the evaporation of moisture thereby induced.

Upon this basis it may be noticed that a current of saturated air at 100° would neither remove heat by its contact nor by induced evaporation, and consequently would be incapable of producing a cooling effect, while as the temperature or the dew point should fall, the current would become a pleasant one. With a high temperature and dry air, the cooling effect of a current of air (even at 100°) may be very pleasant in the sensation, but will be attended with sun-burning (even without exposure to the sun), and blisters will be produced by the excessive deprivation of moisture from the cuticle or surface of the skin. With 80° of temperature and a high dew point, a strong breeze is not unpleasant, nor likely to be injurious after the person shall have acquired some *accustomed* habit of body to endure it: but at 70° and a low dew point, which is the only possible condition of heated air in mid-winter, the annoyance of a current of even five feet per second and its unhealthiness are positive facts.

§ There remain to be considered two more relations of moisture in air, to health and comfort. First, the effect of evaporation of water by the air itself in summer, in reducing the temperature to one of comfort: and secondly, the effect on the moisture condition of the air of summer, when it is attempted to cool air by artificial means.

The cooling of air, by spontaneous evaporation from extended surfaces, is of frequent practice in hot countries by the wealthy inhabitants near the banks of rivers where the water supply is abundant. The condition of the air which makes it practicable is one of great heat, and of a relatively low dew point; and the summers of Egypt and of parts of India, especially of Bengal, give opportunity to employ this method of cooling air. If it is accepted that the temperature of the air in the shade, in the localities referred to, will sometimes run from 85° to 105° for many consecutive hours, accom-

panied with, say, 50 per cent. of moisture for the 85° of temperature, or, say, 30 per cent. for the 105°, then the evaporation of moisture from wet surface can be relied upon to produce a comparatively comfortable atmosphere. Air at 85°, with 50 per cent. of moisture, has quite exactly the same quantity of moisture, per given volume of air, as that at 70° and 70 per cent. of moisture. So that if it could be cooled *without* adding moisture at all, it would then reach the point of comfort for the clothed inhabitant of the temperate zone. If the dew point of 85° is brought up to 80 per cent. or above, the air becomes intolerably sultry, and at 90 per cent., quite suffocating; so that the greatest addition of moisture practicable to the supposed air of 85° and 50 per cent. dew point, may be taken as 10 per cent., or 1¼ grains to the cubic foot. The resulting figures which the latent heat demanded for the evaporation of these 1¼ grains of moisture into the air supposed, is 74½°, and 82 per cent. of humidity. How far this condition of the air may be more comfortable than the original one of 85° and 50 per cent. of humidity, is questionable; but it is apparent that the limit of possible cooling of air of 85°, by evaporation of moisture, is found when its humidity is not to exceed 50 per cent. of saturation. A similar computation applied to air of 105° (in which air there is a little more moisture than in that supposed at 85°) gives, for the addition of 1¼ grains of moisture to the cubic foot, air of 94½° temperature and 48 per cent. of humidity—an atmosphere which *may* be, in some degree, more comfortable to a person at rest than the normal one. It is evident, that for efficiency in cooling air of 105° by evaporation from moistened surfaces, the humidity of the air to be cooled should be less than 30 per cent. As to ultimate healthfulness of the moistened air, it *seems* to be unquestionable that the supply of moisture ought to promote disease.

We have, however, in each year in our country, a few days or parts of days (perhaps, in the Southern Middle states, ten to twenty days in different years), when the range of thermometer and the dew point make it feasible to adopt this means of reducing the apparent heat of the air. The attempt has been frequently made, with provoking failure to the projectors. Its success depends upon not only the exact condition of relative humidity and temperature, but also on the proportion of surface of evaporation to the quantity of air to be supplied. The Indian ratio is one or two persons to six to eight square yards of wet surface. But the most provoking cause of

failure has been, that while there are ten to twenty hot dry days in any year, there are also twenty to thirty hot damp ones, and the application of the *cooling* apparel to the hot air on these days, has produced such an effect of sultriness that the whole has met with instant condemnation.

The last relation of moisture to air to be considered at this time is that which proceeds from the effort to cool air artificially. The fallacies of the attempts to effect this purpose can be made very apparent. Even the smallest decrement of heat is obtained only at great cost. The *quantity* of cooling of air in summer is, to be sure, only about one-fourth that of heating in winter. Taking the ideal temperature of 70°, there may be 15° to come off in summer as generally as 60° to be added in winter, and supposing iced water to be the cooling medium, and steam of low pressure to be the heating one, the relation of difference of temperature of the air to be cooled or heated to that of the iced water or steam, is such, that about the same extent of surface would be required in either case to transfer the heat. But a pound of coal produces in ordinary steam boilers, quite 9000 units of heat on the average, while a pound of ice (in cooling to 60°, let us say), will produce only 170°, so that about 54 pounds of ice would be demanded to effect the transfer of an equal quantity of heat, to what would be effected by 1 pound of coal; or, accepting the one-fourth cooling effect, then 13½ pounds of ice would be demanded for the cooling of air in summer against each pound of coal required for warming in winter. Unfortunately for the proposition for cooling *air* in summer, even this statement is too favorable, for the requirement will be found that the air must not only be cooled, but must be divested of a portion of its moisture, unless the cooled air is deemed satisfactory in the form of a cloud of vapor. Air at 85° and 70 per cent. of humidity must be taken to be cooled to 70° and 70 per cent. of humidity, and one and one-fourth times as much cold, will be demanded to condense the vapor 2·3 grains per cubic foot, as that which is requisite to cool the air the 15° supposed. This leaves the ratio of ice needed to obtain a spring condition for the air on a hot day in summer, to be that of 30 to 1 of coal usually demanded to heat air on a cold day in winter, or assuming that the air on such a day is so dry that no moisture should be removed, about 15 to 1. Our ideas of the necessities of civilized wants, as compared with civilized luxuries,

scarcely yet reach high enough to warrant the expenditure of money to cool air under the circumstances stated.

In view of the great cost of cooling air by ice, it has been proposed to cool it by mechanical means on a large scale. Air, if compressed, becomes sensibly hotter. In fact the compression can be carried to the extent that the heat will ignite tinder, as the cigar lighters of twenty or thirty years since bear witness. And it has been proposed to use large air pumps which shall compress the air until its temperature is elevated sufficiently for it to give off heat to surfaces cooled by currents of water, at such temperature as water is to be had from streams or aqueducts in summer. This compressed air, when deprived of a portion of its heat, is then allowed to expand, and the result is a cooler air. This process has, in reality, much merit, and it is probable that the cost of producing cold in this way, compares favorably with the use of ice; in fact it has been shown that ice itself may be manufactured with profit by this process in some localities, where transportation enhances the price of ice largely. But it is preposterously expensive in apparatus and in cost of working as a means of cooling air in the great quantities demanded for ventilation, and the humidity of the cooled air would still be objectionable. The comparatively high temperature of the surface for cooling the air would fail to be very efficient in condensing the vapor thoroughly. In both the methods of cooling air, whether by ice or by water (of which great quantities would be needed), the cooling surface must be copper, brass or tin, as the rusting of iron, when exposed to condensing vapor, is extremely rapid.

The most probable result of cooled air would be a thunder-cloud in miniature. The atmosphere on one of our hottest and most sultry days of summer is on the verge of a tempest. Cooling of air of 85° to 90°, to the extent of 20° or 30°, produces a dense mist of supersaturated cooled air. The equilibrium of the atmosphere on a still, clear summer day, when every growing thing on the surface of the ground is supplying moisture, and the radiation of the ground itself is supplying heat to increase the relative levity of the strata of air next the ground—the equilibrium of such an atmosphere is very unstable. Let an upward flow be established anywhere, and the air will rush in all directions along the surface to supply the partial vacuum. The ascending column, as it reaches the region of lower barometrical pressure, will expand, become sensibly cooler, and in a short five to

eight miles of height, the region of frost and ice will be reached, and hail-stones will be returned from the condensation of the transparent vapor which had existed in the air when it left the surface of the ground. The writer once saw in a little ball-room, on a Christmas Eve, a miniature snow-storm deposit a little bank of snow, from the opening of windows to air the room, when the dancers had retired; the night being a clear moonlight one, with the thermometer a little above zero.

The difficulty of absence of moisture in air that is heated in winter is a matter to be disposed of with some happiness, by asserting it is not wanted, but the objection of presence of moisture in cooled air can be only overcome by not cooling the air. It does not seem that the successful cooling of our summer air, so as to produce a comfortable or healthful condition at spring temperatures, has any probability of accomplishment.

Quoting as an appropriate final remark the words with which I concluded another paper having an especial application to a system of ventilation: "I will not follow further the proposition to change the seasons into a perpetual springtime—practical ventilation is the supply in dwellings, of an abundance of fresh air at the several seasons, warmed to the temperature of comfort in winter, and supplied in quantity to the volume of comfort (as near as possible of the quality and condition of out of doors in the shade) in summer. The truth is, all our heating and ventilating appliances are the compromise of condition—a truth extending beyond all mechanical operations to the phenomena of nature itself."